# ESTIMATING RELATIVE DRIVER FATALITY AND INJURY RISK ACCORDING TO SOME CHARACTERISTICS OF CARS AND DRIVERS USING MATCHED-PAIR MULTIVARIATE ANALYSIS

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## ABSTRACT

Characteristics of cars, such as mass and age, play a significant role in crash severity, but their effect are difficult to quantify because of the great number of factors altering the outcome of a real world accident. In order to focus on the crashworthiness of cars, we examine risk factors of severity suffered by the drivers involved in two-car accidents recorded by the police between 1996 and 2000 in France. From them, we build three matched case-control studies where both drivers have different severity levels: killed or injured vs. uninjured; severely injured vs. slightly injured; and killed vs. injured. Odds-Ratios are estimated by conditional logistic regression.

The risk of being injured decreases with the weight of the car, coming to six times lower when driving a 1200 kg or more car compared to a 800 kg or less car. The risk of being killed rather than injured increases with the age of the car, reaching the highest value of height when comparing 1990 or before cars to the most recent ones. As expected, highest risks of death or injury are shown for side-impacted cars, seat belt wearing is confirmed as being very protective and drivers of vehicles with frontal airbag are less often injured. The risk of being injured or killed increases with the age of the driver, and is higher for women. These characteristics of drivers are associated with both their way of driving and their capacity to withstand an impact, and it was then necessary to adjust our estimates on them.

Our results show that recent cars provide a better protection, but confirm that the compatibility of cars with each other according to their weight is a big issue. It also corroborates the necessity of adaptative safety devices for taking the characteristics of a car occupant into account.

## INTRODUCTION

For a car occupant involved in a road traffic crash, the outcome depends on the strength of the impact, the capacity of the car to protect them against this strength, the capacity of the occupant themselves to withstand the impact and the efficacy of the rescue organisation and the post trauma medical care. The strength of the impact, i.e. the energy disseminated inside the vehicle, depends on crash conditions, i.e. mainly on directional forces, involved masses and decelerations (and hence on speeds of vehicles at the time just before collision).

The key issue when we are specifically dealing with factors linked to vehicle crashworthiness or relative frailty of its occupants, is to succeed in measuring these factors under non-experimental conditions while at the same time taking the strength of the impacts into account. Outside of using controlled experimental conditions, this target is impossible to reach but we can come close to it by comparing victims involved in the same accident. To this end, we choose to examine differences of severity suffered by the drivers of two cars which collide with each other. The basic idea is that these pairs of drivers have suffered impact's strength much closer on average than drivers involved in different accidents. This is also true for the rescue intervention and the post trauma medical care. The examination of within pairs differences allows one to highlight the influence of some characteristics of the driver and their car on their condition after the crash. These same characteristics are also examined for a second kind of accident: those involving a single car. This additional analysis allows a clearer interpretation of the results for the first kind of accident, we can discuss on the one hand what is purely due to the driver's resistance and their car in terms of its secondary safety, and on the other hand what is more the result of their behaviour.

The aim of this research is to underline the differences in vulnerability of car drivers according to their age and gender, and according to some of the characteristics of their cars which are linked to their crashworthiness.

## MATERIALS AND METHODS

### Data

The study uses road traffic injury accidents recorded by police forces between 1996 and 2000 in France. Data computerized from these police records includes information on accident characteristics (location, date and time, weather conditions, type of collision, type of road, traffic conditions, roadway condition), vehicles involved

(category, age, car model identification number, impacted obstacle) and people involved (age, gender, occupational group, seat belt use). Contrary to similar data records in some countries, no estimates concerning energy equivalent speed or change of velocity during impact (Vallet et al. 1999) are provided.

Every person involved in a road accident is likely to be either killed, immediately or within the six days following the crash, or severely injured, i.e. whose health state requires more than six days of hospitalisation, or slightly injured, i.e. whose health state requires some medical care but no more than six days of hospitalisation. The data collection process also records non injured people since they were occupants of a vehicle involved in an injury accident, i.e. with at least one injured people. As every vehicle has a driver (the case where a parked vehicle is crashed into by another vehicle is separately recorded), we always know their characteristics even if he is not injured, which is more questionable for other car passengers.

From our five observation years, we firstly select all accidents involving two cars (and only two), without any involved pedestrian. Among them, we select accidents where both drivers have different severity levels. Hence we build three matched case-control studies: the first one with a killed or injured driver as the case and a non injured driver as the control; the second one with a severely injured driver as the case and a slightly injured driver as the control; and finally the third one with a killed driver as the case and an injured driver as the control. The resulting three accident samples do not overlap one another and allow us to examine the consistency of the results according to the observed severity level. This sample selection process leads us to exclude each accident in which the two car drivers have the same severity level. In this way, we are able to estimate the risk of being injured (rather than uninjured) even from our injury accident recording. This matching process, widely used in the biomedical area (Breslow & Day 1980), was firstly used for road accident studies by Hutchinson (Hutchinson 1982) and Evans. (Evans 1986) Cummings recently summarized the relevant statistical analysis methods available (Cummings et al. 2002).

A second analysis is carried out for accidents involving only one vehicle, always focusing on the driver. As only injury accidents are recorded, uninjured drivers are recorded only if there is an injured or killed passenger inside the car. Hence the previously used criteria "injured/uninjured" could be biased. Furthermore, police records tend to under-estimate non-fatal accidents when there is no third party (Laumon & Martin 2002). Consequently we only focus on the risk of being killed rather than injured in single-car accidents.

**Statistical analysis**

Concerning the three matched case-control studies, Odds-Ratios (OR) are estimated by the ratios of the two types of discordant pairs for the univariate analysis (Mantel & Haenszel 1959), and by conditional logistic regression for the multivariate analysis. The models are fitted with STATA (STATA 1999) and SAS Software (SAS 1999) after a data transformation explained by Holford (Holford et al. 1978) and Hosmer (Hosmer & Lemeshow 2000). The tables show OR maximum likelihood estimates and their 95 percent confidence intervals. Every quantitative variable is cut into n values, introduced in the regression as (n-1) dummy variables and tested as a whole by comparing the likelihood of the two corresponding nested models (McCullagh & Nelder 1989). Concerning the single car accident analysis, OR are estimated with an unconditional logistic regression, with the same coding and test process.

**Available variables**

The severity difference between the drivers is examined according to three characteristics: on the one hand gender and age (divided into three age-groups), and on the other hand the safety belt wearing. Cars are characterized by their first registration year. Each car model is also identified by a vehicle identification number necessary for French administration approval, but this number is not always available and sometimes wrong when compared to a reference list. As this specific information is missing for about one in two cars, this means that this information is only available on average for one in four two-car crashes. Therefore this leads to present two levels of analysis, the first one with the first year of registration only to characterize the car, and the second one with additional information available through the vehicle identification number, such as the weight, the power or the engine capacity, but for a smaller number of observations.

Lastly, even if the matching process leads to equal accident conditions, it is still necessary to take the main impacted location on each car into account. This variable is cut into four categories: front impact (front, front right or front left impact), right side impact, left side impact (driver side in France) and rear impact (rear, rear right and rear left impact). In the end, the driver airbag equipment is known for a very low number of cars, but we test its effect and discuss this extra device for the two kinds of accidents in the corresponding sub-samples.

**RESULTS**

Among the 633,590 injury accidents recorded in France by the police between 1996 and 2000, 153,722 are two-car accidents. Drivers have

different injury severity levels for 97,153 of these accidents, which gives information for the matched data analysis. After removing observations with missing values (mainly because of seat belt wearing variable), the analysis is performed on 61,515 accidents in which a single driver is injured, 6,337 in which one driver is severely injured and the other one slightly injured and 2,546 in which one is killed and the other one injured. The distribution of these factors is shown in table 1 for all cars and drivers involved in two-car crashes. Distributions of variables are very similar in the three nested samples except for the first registration number for the most recent cars, which is due to a change in the codification of Vehicle Identification Numbers in July 1997.

**Table 1.**
**Distribution of some characteristics for drivers and cars involved in two-car accidents, percentages, France, 1996 to 2000**

| | | | All drivers | Matched drivers with different outcome (1) | (1) and known car characteristics |
|---|---|---|---|---|---|
| | | | % (N=307,444) | % (N=194,305) | % (N=89,233) |
| Car | First registration year | 1990 or before | 38.8 | 38.9 | 42.8 |
| | | 1991-1992 | 13.5 | 13.4 | 16.4 |
| | | 1993-1994 | 13.1 | 13.0 | 15.5 |
| | | 1995-1996 | 14.8 | 14.8 | 16.9 |
| | | 1997-1998 | 10.0 | 10.1 | 6.6 |
| | | 1999-2000 | 4.1 | 4.1 | 0.6 |
| | | *Unknown* | *5.7* | *5.7* | *1.2* |
| | Main impact location | Front | 69.9 | 69.7 | 70.8 |
| | | Rear | 13.4 | 13.3 | 12.2 |
| | | Right side | 5.4 | 5.1 | 5.4 |
| | | Left side | 7.6 | 8.2 | 8.8 |
| | Car weight | Less than 800 kg | 21.7 | | 22.4 |
| | | [800-1000 kg[ | 41.6 | | 40.9 |
| | | [1000-1200 kg[ | 23.4 | | 23.1 |
| | | 1200 kg or more | 13.1 | | 13.5 |
| Driver | Age (years) | 18-44 | 67.6 | 67.1 | 66.8 |
| | | 45-64 | 23.9 | 24.2 | 23.7 |
| | | 65 and more | 8.5 | 8.7 | 9.5 |
| | gender | Males | 68.7 | 67.7 | 66.6 |
| | | Females | 31.3 | 32.3 | 33.4 |
| | Seat belt wearing | Yes | 81.4 | 81.1 | 83.7 |
| | | No | 4.4 | 4.7 | 4.8 |
| | | *Unknown* | *14.2* | *14.2* | *11.4* |

The model shown in table 2 includes all factors significant as a whole, as well as the age-gender interaction which is significant except for the sample comparing fatalities and casualties.

Comparing cars from and before 1990, we observe that the risk of being injured decreases with the age of the car. This trend is sharper when we consider the more severe outcomes. Hence, the risk of being killed is about five times lower for a driver of a post 1998 year car, hitting (or being hit by) a pre 1991 year car.

For these two-car accidents, table 2 shows that the risk of the driver being injured is the lowest in the case of a front impact, chosen as the reference level. Let us note that this does not mean in any way that a front to front accident causes less severe consequences than an other kind of accident. The percentage of two-car accidents with at least one killed driver is greater than 4.3% for a front to front impact, 5.3% for a front to side impact, and slightly less than 1% for a front to rear impact. However, when impact locations are different, the probability to be injured or killed is lower for the front hitting car driver. The risk of being injured is higher for a rear impact. It is also higher for a side impact, especially for the driver side. The risk of being killed is very high in the case of a side impact.

The interpretation of gender and age effects on the outcome is more complex because of the significant interaction between them. Concerning men, the risk of being injured increases with the age. This gradient is sharper for the risk of being killed, and the risk of being severely injured instead of slightly injured. Same trends are observed for women, but starting from a higher reference level. Compared to young men, the risk of being injured is four times higher for young women, the risk of being killed is around one and a half times higher and the highest risk (9.7) is for women aged 65 years or more.

**Table 2.**
**Two-car accidents – risk estimates of being injured instead of uninjured, severely injured instead of slightly injured, killed instead of injured. OR and 95% Confidence Intervals estimates with conditional logistic regression, France, 1996 to 2000**

| Matched data | | | Injured/uninjured | | Severely/slightly injured | | Killed/injured | |
|---|---|---|---|---|---|---|---|---|
| | | | N=61,515 | | N=6,337 | | N=2,546 | |
| | | | OR | 95% C.I. | OR | 95% C.I. | OR | 95% C.I. |
| Car | First registration year | 1990 or before | 1 | | 1 | | 1 | |
| | | 1991-1992 | 0.92 | 0.88, 0.95 | 0.64 | 0.57, 0.72 | 0.71 | 0.56, 0.90 |
| | | 1993-1994 | 0.79 | 0.58, 0.82 | 0.61 | 0.54, 0.69 | 0.51 | 0.41, 0.65 |
| | | 1995-1996 | 0.72 | 0.69, 0.75 | 0.50 | 0.45, 0.57 | 0.38 | 0.30, 0.48 |
| | | 1997-1998 | 0.62 | 0.59, 0.65 | 0.36 | 0.31, 0.41 | 0.21 | 0.16, 0.58 |
| | | 1999-2000 | 0.56 | 0.52, 0.60 | 0.30 | 0.24, 0.38 | 0.19 | 0.12, 0.30 |
| | Main impact location | Front | 1 | | 1 | | 1 | |
| | | Rear | 2.06 | 1.98, 2.13 | 1.30 | 1.06, 1.60 | 3.09 | 1.72, 5.54 |
| | | Right side | 1.39 | 1.32, 1.48 | 2.47 | 2.07, 2.94 | 12.13 | 8.33, 17.7 |
| | | Left side | 2.48 | 2.36, 2.60 | 4.06 | 3.45, 4.79 | 13.56 | 9.04, 20. 3 |
| Drivers | Males | 18-44 years old | 1 | | 1 | | 1 | |
| | | 45-64 years old | 1.02 | 0.98, 1.06 | 1.27 | 1.13, 1.42 | 1.75 | 1.41, 2.17 |
| | | 65 or more | 1.70 | 1.61, 1.79 | 2.95 | 2.50, 3.47 | 5.20 | 3.82, 7.09 |
| | Females | 18-44 years old | 3.94 | 3.80, 4.09 | 1.55 | 1.40, 1.72 | 1.49 | 1.20, 1.84 |
| | | 45-64 years old | 3.96 | 3.76, 4.14 | 2.53 | 2.16, 2.96 | 2.96 | 2.16, 4.06 |
| | | 65 or more | 4.92 | 4.48, 5.41 | 7.12 | 5.23, 9.68 | 9.76 | 5.58, 17.1 |
| | Seat belt wearing | Yes | 1 | | 1 | | 1 | |
| | | No | 5.89 | 5.41, 6.41 | 3.23 | 2.66, 3.92 | 7.46 | 5.43, 10.3 |

**Table 3.**
**Two-car accidents – risk estimates of being injured instead of uninjured, severely injured instead of slightly injured, killed instead of injured. OR and 95% Confidence Intervals estimates with conditional logistic regression, France, 1996 to 2000. Model taking account of car weight**

| Matched data | | | Injured/uninjured | | Severely/slightly injured | | Killed/injured | |
|---|---|---|---|---|---|---|---|---|
| | | | N=18,990 | | N=2,723 | | N=1,047 | |
| | | | OR | 95% C.I. | OR | 95% C.I. | OR | 95% C.I. |
| Car | First registration year | 1990 or before | 1 | | 1 | | 1 | |
| | | 1991-1992 | 1.06 | 0.98, 1.13 | 0.75 | 0.62, 0.90 | 0.77 | 0.50, 1.17 |
| | | 1993-1994 | 1.01 | 0.93, 1.08 | 0.83 | 0.69, 1.01 | 0.63 | 0.42, 0.96 |
| | | 1995-1996 | 0.99 | 0.92, 1.07 | 0.67 | 0.55, 0.81 | 0.60 | 0.40, 0.91 |
| | | 1997-1998 | 0.90 | 0.81, 1.01 | 0.62 | 0.46, 0.83 | 0.32 | 0.17, 0.61 |
| | | 1999-2000 | 0.93 | 0.67, 1.29 | 0.53 | 0.23, 1.21 | 0.12 | 0.01, 1.12 |
| | Main impact location | Front | 1 | | 1 | | 1 | |
| | | Rear | 2.16 | 2.01, 2.31 | 1.30 | 1.11, 2.32 | 2.77 | 0.97, 7.92 |
| | | Right side | 1.35 | 1.21, 1.50 | 2.47 | 2.50, 4.42 | 16.50 | 8.11, 33.5 |
| | | Left side | 2.60 | 2.38, 2.84 | 4.06 | 4.08, 7.02 | 19.79 | 9.70, 40.4 |
| | Weight | Less than 800 kg | 1 | | 1 | | 1 | |
| | | [800-1000[ | 0.57 | 0.54, 0.61 | 0.47 | 0.39, 0.56 | 0.45 | 0.29, 0.69 |
| | | [1000-1200[ | 0.34 | 0.32, 0.37 | 0.22 | 0.18, 0.28 | 0.12 | 0.07, 0.20 |
| | | 1200 and more | 0.16 | 0.15, 0.18 | 0.11 | 0.08, 0.15 | 0.04 | 0.02, 0.07 |
| Drivers | Males | 18-44 years old | 1 | | 1 | | 1 | |
| | | 45-64 years old | 1.27 | 1.18, 1.36 | 1.61 | 1.33, 1.94 | 3.60 | 2.36, 5.50 |
| | | 65 or more | 1.71 | 1.55, 1.87 | 2.92 | 2.21, 3.86 | 10.24 | 5.60, 18.7 |
| | Females | 18-44 years old | 3.45 | 3.22, 3.69 | 1.68 | 1.42, 2.00 | 1.52 | 1.03, 2.34 |
| | | 45-64 years old | 3.80 | 3.44, 4.18 | 2.63 | 2.04, 3.39 | 3.51 | 1.95, 6.33 |
| | | 65 or more | 3.91 | 3.30, 4.64 | 5.37 | 3.34, 8.62 | 6.99 | 2.57, 19.0 |
| | Seat belt wearing | Yes | 1 | | 1 | | 1 | |
| | | No | 5.98 | 5.07, 7.04 | 3.89 | 2.84, 5.33 | 8.83 | 4.87, 16.0 |

Finally, as expected, non-restrained drivers are five times more often injured than restrained ones, and more than seven times more often killed. The value of the risk of being severely injured rather than slightly injured is curiously lower.

In order to be more specific about involved cars, we use the vehicle identification number available in the data records. Due to missing values, this leads us to deal with three sub-samples with respective sizes of 18,990, 2,723 and 1,047 accidents. The OR estimates after introducing the same previous variables are very stable and the corresponding table does not show added value compared to table 2. This stability is going to allow us to attribute possible changes to the factors we are going to add, and not to the lower number of usable observations due to the inclusion of these factors.

Among the three additional factors available through the vehicle identification number, with the same additional parameters number included in the model and using the maximum likelihood as the statistical criteria, the car weight is the one most associated to the severity. This upper statistical significance was expected because the weight is associated both with the car speed capability and also with the dispersion energy impact capacity. The new model estimates are shown in table 3.

As expected, all OR estimates are very close to the previous values, except for the first year of registration variable. The car age is no more significant according to the injured/uninjured criteria, but stays significant for the other severity criteria. The risk of being injured is six times lower for the driver of a car weighing more than 1200 kg, compared to a car weighing less than 800 kg involved in the same two-car crash. The risks of being severely injured or killed are much higher.

Finally for the two-car crashes analysis, we consider the effect of a front airbag, which is becoming more and more available on the French market. From the technical information of the car manufacturers, we have identified models with front airbag or not for the most common cars. This information is known for 15% of crashed cars. Among them, 2,541 cars are equipped with a front airbag. This characteristic is introduced in the previous logistic model and the sample size is reduced to 1,977 accidents with drivers injured or not (the two other samples are too small to be statistically relevant). The risk of being injured, adjusted for all the other factors, is significantly lower when the car is equipped with an airbag (OR=0.56, 95% C.I.: 0.37, 0.83). This decrease is higher when we consider the sub sample with only the 902 front to front impacts (OR=0.40, 95% C.I.: 0.21, 0.75).

**Additional analysis**

In order to be able to have a clearer interpretation of the results shown in table 3, we select single-car accidents. The results shown in table 4 are fitted with unconditional logistic regression for the 29,794 single-car accidents. In order to take accident circumstances into account better (which was previously useless because of the matching process), we fit the model to the road type (motorway, main road, minor road, street) and the narrow fixed obstacle impact (tree, pole) in addition to the same previous factors.

The age of the car has no significant effect on the severity. The risk of being killed is greater for higher weight vehicles. It is higher for side impact than for front impact, and much lower for rear impact (but this is a very rare case). The risk increases with the age of the driver, and is lower for women drivers. The seat belt wearing appears markedly protective. The front airbag device has no significant effect on the 9,178 single-car accidents for which this information is available.

**Table 4.**
**Single car accidents: Risk for the driver to be killed according to some characteristics. Confidence Intervals estimates with unconditional logistic regression, France, 1996 to 2000**

| | | | Killed/injured N=29,794 | |
|---|---|---|---|---|
| | | | OR | 95% C.I. |
| Car | First registration year | ≤ 1990 | 1 | |
| | | 1991-1992 | 1,08 | 0.96, 1.22 |
| | | 1993-1994 | 1.01 | 0.90, 1.15 |
| | | 1995-1996 | 1.05 | 0.93, 1.20 |
| | | 1997-1998 | 1.06 | 0.89, 1.28 |
| | | 1999-2000 | 0.73 | 0.39, 1.37 |
| | Main impact location | Front | 1 | |
| | | Rear | 0.74 | 0.58, 1.03 |
| | | Right side | 1.74 | 1.48, 2.04 |
| | | Left side | 2.87 | 2.50, 3.29 |
| | Weight | ≤ 800 kg | 1 | |
| | | [800-1000[ | 1.16 | 1.03, 1.31 |
| | | [1000-1200[ | 1.31 | 1.14, 1.50 |
| | | ≥ 1200 | 1.29 | 1.09, 1.52 |
| Driver | gender | male | 1 | |
| | | female | 0.67 | 0.60, 0.74 |
| | Age (years) | 18-44 | 1 | |
| | | 45-64 | 1.21 | 1.17, 1.26 |
| | | ≥ 65 | 1.30 | 1.26, 1.35 |
| | Seat belt wearing | Yes | 1 | |
| | | No | 5.00 | 4.54, 5.26 |

*Also adjusted for road type and fixed obstacle impact.*

## DISCUSSION

In traffic safety research, it is usual to classify all factors liable to change the occurrence or the outcome of a crash under three categories, either human, vehicle and equipment, or environment. Each of these factors is chronologically categorised as pre-crash, crash, or post-crash, giving a 3x3 matrix defined by Haddon (Haddon 1972). The comparison between single and two-car accidents leads to some considerations on the driver's behaviour in the pre-crash period, and the outcome is dependent on the possible time of hospitalisation in the post-crash period. However, our study mainly focuses on the crash period about the human , and vehicle and equipment characteristics.

Our results are based on police record data, which is known to be incomplete when compared with hospital based data (Laumon & Martin 2002). However, fatal accidents are quite well recorded in France as in other developed countries (Elvik & Mysen 1999) and our comparison between single and two-car fatal accidents should not be biased according to the outcome used. The fact that some discrepancies exist concerning the estimation of the length of hospital stay used to classify the level of severity (Laumon & Martin 2002) should not cause a bias either, as there is no reason that this could systematically and differently affect the two drivers involved in the same crash.

Road accidents identified as suicides are excluded from police records, but hidden suicide intentions could be wrongly included especially for single car accidents. No data is available but some authors (Ahlm et al. 2001; Hernetkoski & Keskinen 1998) estimate the proportion of hidden suicide among accident data comprised between 2 and 8%, with a majority of male drivers. This could bias our estimates for single car accidents, but probably not in a significant way.

The comparison between the severities suffered by the two drivers involved in the same accident highlights the differences in crashworthiness of the cars and in relative fragility of the drivers for (almost) the same impact. It then appears that, in the case of a collision between two cars, the heaviest one provides the best protection. This parameter has been shown more statistically relevant than the engine capacity and the power, which was expected as the impact energy dissipation is closely linked to the weight (Evans & Frick 1992; Evans & Frick 1993; Thomas & Frampton 1999). Because of the characteristics of cars associated with weight, such as stiffness, structure and geometry, we think that differences of severity observed are due to better protection of the driver of the heavier car but also to an increased risk for the driver of the lighter car. Our results, which take age and gender of the drivers into account in real world accidents, confirm this problem of compatibility between cars evaluated by many experimental and observational studies (Edwards et al. 2001; Gabler & Hollowell 2000; Zeidler & Knoechelmann 1998).

Besides, cars seem to better protect their drivers when they are recent. This result was expected, as the recent developments of structures of cars focus on the increase of the impact energy absorption capacity, on the minimization of intrusion phenomena and on the improvement of their safety equipment (which allows car occupants to tolerate the fact that car structures are more and more stiff). However, it is important to point out that these changes have resulted on average in an increase in car weight, which is also due to comfort equipment (air conditioning, soundproofing), anti-pollution devices (catalytic converter) or increase in engine power. This positive correlation possibly makes the car age effect on the risk of being injured disappear, but the effect of the car age and the weight are still significant for the risk of being killed rather than injured, or severely injured rather than slightly injured, which shows that both are simultaneously important. The observed "dose-response" effects, for the car age and its weight as well as for the severity criteria, are a strong argument to the results value, even if car characteristics are only defined by rough proxy variables.

Furthermore, the impact location allows us to better take into account the impact configuration. In the case of a front to rear impact, the consequences are more severe for the leading car, in accordance to the study of Khattak (Khattak 2001). In the case of a front to side impact, the risk of being killed or injured is much higher for the side impacted driver, especially for their side. Further work is needed to measure a possible change in time for this kind of impact, but secondary safety engineers know that side impact improvements are very difficult to obtain.

On the other hand, no difference appears due to the age of the car for single-car accidents, but the most severely injured drivers are more often in the heaviest cars. However, the examination of this type of accidents does not allow us to distinguish between the part of the severity due to the car's capacity to protect its driver and the part due to impact conditions, especially the running speed just before the crash (and hence linked to the way of driving).

The differences in the results for the two types of accidents concerning the male and female drivers can be explained in a similar way: the risk of being killed rather than injured is shown lower for women than for men for single car accidents. This could be due partly to higher impact speeds for

male drivers, which are not considered enough in the logistic model by the simplistic road type effect. On the contrary, by adjusting for the impact's strength, the matched study on the two-car crashes highlights the higher fragility of women, varying according to the severity criteria considered and the age group. This difference has been shown by many authors from fatality accident records (Evans 2000; Foret-Bruno et al. 1990; Mannering 1991). For the particular women group aged 18-44 years, the high value for the risk of being injured could be due either to an overestimation of their injury severity by the police, or to the consequence of an underestimation by men of the same age group of their own condition (Arènes et al. 1997). This higher frailty of women can be explained by biomechanical considerations, such as a lower capacity to endure impacts, which has been experimentally shown for instance for thorax bones (Foret-Bruno et al. 1990), or by the differences in mass or stature. Osteoporosis could be another explanation of the higher relative risk for older women, but further study is needed to estimate its real effect, with more specific information on bone fracture occurrence. The fact that no significant interaction between seat belt wearing and gender has been shown is contrary to the hypothesis that the difference in seat belt wearing habit could be an explanation of the difference in frailty between genders. Compared to men, women, on average, drive smaller cars and more often in urban areas. It is then essential to take these factors into account to show the real difference between men and women, which has been done with the design study and the multivariate analysis.

Concerning the age effect, the significant age-gender interaction leads to two separate Odds-Ratios for men and women. The severity increase according to age, shown by many authors (Evans 2000; Li et al. 2002), is confirmed for the two genders, and is highest when considering the risk of being killed. It is important to point out that driver age and gender effects shown in this study do not concern effects of these factors on the probability to be involved in an accident, as this is dependant from the exposure (kilometres driven), the road type or the driving behaviour (running speed, risk taking, etc.). These aspects have been studied by other authors (Claret et al. 2002; Dellinger et al. 2002; Li et al. 1998; Massie & Williams 1993; Perneger & Smith 1991) in order to measure the global effect of these factors on the road safety.

Even if the quality of the seat belt wearing information is known as being far from perfect, the seat belt effect is indisputable for the two types of accidents, as widely shown in many papers (Chipman et al. 1995; Cummings et al. 2001). Finally, even though the information on airbag equipment is often missing, the vehicles equipped with an airbag are shown to give better protection, in accordance again with many studies (Barry et al. 1999; Braver et al. 1997; Evans 1989). This benefit is shown higher for front to front impacts, which was expected, as front airbags are made to expand, above some deceleration threshold, in case of a frontal impact and not for a side impact. This result is interesting, as it is shown for equivalent impact conditions between two vehicles, but the available information is not specific at all, as we do not know if the airbag really expanded during the crash. More than the airbag effect, it is better to interpret it as a global effect for an airbag equipped car, since this equipment has often been put in at the same time as vehicle structure changes were made.

To sum up our results, modern cars seem to offer better protection to their drivers, and probably to all their occupants, but this improvement is only shown for the comparison of drivers involved in the same collision and not for the single vehicle accidents. A lot of authors have described changes in the behaviour of people driving potentially safer cars, or driving in safer traffic conditions (Fosser et al. 1999; Martin 2002). Many drivers keep their perceived risk constant, which can cancel (and even inverse) the potential benefit brought by vehicle and infrastructure improvements, because of an increase in running speed or a lower attention level. This homeostatic risk phenomenon could widely explain the observed differences between the two kinds of accidents.

If recent cars seem to provide a better protection, the compatibility of cars with each other is shown as a big issue, as the lighter car is very disadvantaged compared to an heavier one in the case of an accident. The observed severity is higher for male drivers and heavier cars in single vehicle accidents, when the matched two car accidents study shows that men are more impact-resistant and that heavier vehicles offer a better protection. Thus we could think of an ideal scenario which could minimize the consequences of an accident: a driver having the "young man crashworthiness", driving on average more like a woman than a man, with a modern (but light) car. The change in driver behaviour, especially for a more accurate risk perception and speed adjustment is the most difficult objective to achieve. For lack of improvement of car drivers physical resistance, car manufacturers still have to be encouraged to continue theirs works towards adaptative safety devices, such as "intelligent" expanding airbags or seat belts able to take the characteristics of a car occupant such as their weight or their seat position into account.

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